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Using represented bodies in Renaissance artworks to teach musculoskeletal and surface anatomy

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Abstract

Surface anatomy is an important skill for students in preparation for patient care, and peer examination is often used to teach musculoskeletal and surface anatomy. An alternative pedagogical approach is to use bodies represented in artworks. Represented bodies display fictive anatomy, providing students with the opportunity to apply their musculoskeletal knowledge and to think critically when evaluating the anatomical fidelity of a represented body. An elective course at the University of Michigan enabled undergraduate students to analyze the musculoskeletal and surface anatomy depicted in Renaissance artworks. Students traveled to Italy in 2018 ($n = 14$) and 2022 ($n = 15$) to analyze the fictive anatomy portrayed in artistic sculptures and musculoskeletal structures depicted in wax anatomy models and sculpted skeletons. In assignments, students were asked to identify musculoskeletal structures as portrayed in the context of represented anatomy created by Italian Renaissance artists and to assess the fidelity of the depicted anatomy. The students also applied their knowledge of musculoskeletal anatomy to describe body position and evaluate muscle function in their assessments of the accuracy or inaccuracy of the fictive anatomy. The students reported that evaluating the anatomical fidelity of represented bodies in artworks supported their learning of musculoskeletal and surface anatomy, and that their critical thinking skills improved in the course. Evaluation of the anatomical fidelity of represented bodies in artworks is an effective pedagogical approach that can be implemented in art museums as an adjunctive learning experience to deepen students' musculoskeletal and surface anatomy knowledge and further develop their critical thinking skills.

KEYWORDS
anatomy education, art-based pedagogy, arts-based learning, musculoskeletal anatomy, Renaissance art, study abroad, surface anatomy, undergraduate education

INTRODUCTION

The ability to recognize anatomical landmarks on the surface of the body is an important skill for students in the health professions in preparation for patient care (Sugand et al., 2010; Standring, 2012; Azer, 2013). Surface anatomy plays an essential role in clinical practices, such as physical examinations, interventionist procedures, or interpreting diagnostic images (Standring, 2012). Knowledge of

surface anatomy enables a practitioner to identify the anatomical structures that shape the observable body, and to relate observable features to other anatomical structures under the skin. Learning surface anatomy also provides students with an opportunity to apply anatomical knowledge gained through dissection or didactic experiences to the living body in anticipation of professional practice (Boon et al., 2002; McLachlan & Regan De Bere, 2004; Aggarwal et al., 2006; Ganguly & Chan, 2008; Kotzé et al., 2012; Bergman et al., 2013).

Although the importance of surface anatomy in medical and other graduate health profession programs has been acknowledged, the role of surface anatomy in pre-professional undergraduate education is less well established. This is surprising since the musculoskeletal system is an essential component of undergraduate human anatomy courses, particularly in kinesiology and exercise science programs (Viana et al., 2019; Rabattu et al., 2023), and knowledge of musculoskeletal anatomy is fundamental to development of surface anatomy skills (Ganguly & Chan, 2008; Standring, 2012; Bergman et al., 2013; Finn, 2018; Canoso et al., 2020). Thus, incorporating surface anatomy activities into anatomy courses in undergraduate health science programs may be an effective approach to support student learning about the musculoskeletal system. Very few studies, however, have reported the impact of surface anatomy activities on learning the musculoskeletal anatomy in undergraduate education (Diaz & Woolley, 2015; Barmaki et al., 2019).

A variety of pedagogical approaches have been used to teach surface anatomy. A recent scoping review identified approaches to surface anatomy pedagogy that yielded positive learning outcomes (Abu Bakar et al., 2022). Themes emerging in the most effective surface anatomy teaching strategies incorporated contextualized teaching, such as an interactive environment and active learning; experiential learning, providing students with hands-on activities, reflection opportunities and conceptualizing; and learning facilitation with experienced teachers. Methodologies used in studies with effective pedagogies included radiological imaging, applied clinical teaching, peer group interaction, body painting, anatomical drawing, online learning, cadaveric anatomy, and body massage. Improvements in anatomy knowledge and retention were attributed, at least in part, to the use of art-based pedagogies in both undergraduate health science (Diaz & Woolley, 2015; Nicholson et al., 2016) and medical education (Azer, 2011; George et al., 2019). Students at both levels perceived that the art-based pedagogies were helpful for their learning (McMenamin, 2008; Jariyapong et al., 2016), particularly for the musculoskeletal system (Anderton et al., 2016).

Art-based pedagogies, such as body painting (Op Den Akker et al., 2002; McMenamin, 2008; Nanjundaiah, 2012; Aka et al., 2018; Shapiro et al., 2023), drawing (Kotzé et al., 2012; Backhouse et al., 2017; Shapiro et al., 2020), and clay modeling (Bareither et al., 2013; Kooloos et al., 2014) use artistic methods to enhance learning. A common finding in many studies using art-based pedagogies is increased student engagement in the learning activities, assessed as increased enjoyment, interest, motivation or time on task (McMenamin, 2008; Finn & McLachlan, 2009; Nayak & Kodimajalu, 2010; Naug et al., 2011; Diaz & Woolley, 2015; Anderton et al., 2016; Jariyapong et al., 2016; Nicholson et al., 2016; Barmaki et al., 2019). Although increased student engagement with learning activities is a very positive attribute, there are some challenges associated with these pedagogies. For example, identifying surface anatomy on a peer in a class session, with or without subsequent body painting, has drawbacks such as discomfort or embarrassment and learning limitations for the volunteers (Aggarwal et al., 2006; Cookson et al., 2018), unwillingness of some students to volunteer related to cultural and social issues (Aggarwal et al., 2006; Finn, 2010), or other students blocking their view (Bergman et al., 2013). When manipulating materials in arts-based pedagogies, students often work in small groups, and it may be the active learning or group work itself that enhances learning, since many studies have not controlled for these potential effects (DeHoff et al., 2011; Bareither et al., 2013). Further, manipulating an artistic medium may even divide attention between the manual task and the actual learning task (Kooloos et al., 2014). Finally, many studies using arts-based activities report results based on a single workshop or a small number of learning experiences, or on a limited number of musculoskeletal structures (Op Den Akker et al., 2002; McMenamin, 2008; Naug et al., 2011; Kooloos et al., 2014; Jariyapong et al., 2016; Nicholson et al., 2016; Backhouse et al., 2017; George et al., 2019; Shapiro et al., 2023), so the impact of sustained use of the pedagogical approach throughout a course, particularly with regards to the whole body, is rare (Bareither et al., 2013).

Another type of arts-based pedagogy used in the health sciences is engaging with artworks in museums. Typical goals of these learning activities are to help students develop human skills, such as increased empathy, sensitivity, and resilience, and to improve their observational skills (Bardes et al., 2001; Lazarus & Rosslyn, 2003; Naghshineh et al., 2008; Jasani & Saks, 2013; Zazulak et al., 2015; Evans et al., 2018; Gurwin et al., 2018; Agarwal et al., 2020). Since the goals of these learning activities are not anatomical, the artworks viewed by students can be non-representational or do not feature the body anatomically. Although anatomical artworks exist, particularly in the form of historical anatomical illustrations (Ghosh, 2014) and models (Narang et al., 2021), few studies have used anatomy-related artworks or anatomical analysis of artworks in arts-based pedagogy applications (Moore et al., 2011; Speed et al., 2015; Black & Varsou, 2019). To our knowledge, student engagement with artworks to develop musculoskeletal anatomy knowledge and surface anatomy skills has not yet been described in the literature.

An alternative approach is to use bodies represented in artworks as the objects of study. Representations of the nude body in sculptures or paintings provide students with the opportunity to identify surface anatomy features, particularly of the musculoskeletal system, that are portrayed in the artworks. The anatomy depicted in represented bodies is fictive, however, even if the artist's intent is to create "realistic" portrayals of the body (Gombrich, 2000; Summers, 2003; Adkins, 2017). Therefore, analyzing fictive anatomy would enable students to apply their knowledge of musculoskeletal anatomy to identify represented

structures, and then to evaluate the anatomical fidelity of those depicted structures. Engaging with the metaphorical and representational nature of visual art, including its subjectivity and its ambiguous and complex qualities (Haidet et al., 2016), necessitates a type of critical thinking that is not available when examining surface anatomy with living bodies.

Artworks created during the Italian Renaissance provide excellent examples of fictive anatomy in represented bodies because of the shared knowledge and common goals held by many artists and anatomists working at this time. During the Early Modern period (c.1350–1750), artistic practice and scientific inquiry were interrelated projects to better understand the complexity of the human form, both its structures and functions. Artists and anatomists collaborated to produce visual representations that depicted the human body with a high degree of fidelity. Renaissance artists attended dissections and autopsies or conducted them firsthand to produce artworks that could then be used as anatomical training tools (Park, 1994). This includes, most famously, Leonardo da Vinci and Michelangelo Buonarotti (Hall, 2005; Azzolini, 2006; Pesta, 2014). Two prominent university anatomical theaters were built during the Early Modern period in Bologna and Padua (Ferrari, 1987; Klestinec, 2004), which, studied by anatomy students today, draw parallels between learning anatomy in historical and contemporary contexts (Carvalho Filho et al., 2021). Wax anatomy museums in Florence and Bologna (Chen et al., 1999; Maraldi et al., 2000) provide students with additional opportunities to learn from models used during the 18th and 19th centuries (Riva et al., 2010). Furthermore, Renaissance artists and anatomists looked to recently rediscovered classical statuary as models for the exploration of how to represent the body. These models featured kinetic poses that required musculoskeletal knowledge to fully appreciate. The Renaissance's best-known medical treatise, Andreas Vesalius's *De humani corporis fabrica* (1543), exemplifies this with illustrations of bodies in various states of dissection in motion and assuming the poses of famous antique sculptures (Harcourt, 1987).

To explore the feasibility of using represented bodies in artworks as a pedagogical modality for learning surface anatomy, an elective, study abroad course was developed to provide undergraduate students with the opportunity to analyze the musculoskeletal anatomy depicted in Italian Renaissance artworks. Students traveled to five cities in Italy to observe artworks created in antiquity and during the Early Modern period, including represented bodies in artistic sculptures in museums and churches, and musculoskeletal structures depicted in wax anatomy models in museums and on tomb sculptures in churches. The assignments were designed to provide students with the opportunity to apply their musculoskeletal and surface anatomy knowledge by identifying musculoskeletal structures depicted in the artworks and to develop their critical thinking skills by evaluating whether or not the depicted anatomy was realistic. The purpose of this study was to evaluate whether this pedagogical approach to teaching and learning anatomy was effective in helping students deepen their knowledge of musculoskeletal and surface anatomy and think critically about anatomy represented in artworks.

COURSE DESIGN

A faculty-led study abroad course "Art and Anatomy in Renaissance Italy" was developed at the University of Michigan in the School of Kinesiology to provide undergraduate students with the opportunity to apply their knowledge of musculoskeletal anatomy in the context of Early Modern art in Italy. The course was designed by instructors with expertise in anatomy (M.G.) and history of art (W.S. and J.G.). The course was first offered in May 2018 (three weeks) and again in May 2022 (four weeks). Students visited sites in Rome, Florence, Padua, and Bologna in both years, and, in different years, Venice (2018) and Milan (2022). Most sites were selected to meet the anatomy-related learning goals, but other sites were included for cultural learning experiences.

Implementation of the elective course was supported by staff in the School of Kinesiology Global Engagement Office. A global studies vendor was engaged to arrange hotels, transportation, reservations, tickets, and tour guides where needed. An onsite staff person provided by the vendor accompanied the instructors and faculty each day, providing language, culture, transportation, and health and safety support. Students paid a program fee that covered all of the costs of the course except meals, incidental expenses, and transportation to Italy.

The anatomy-related itinerary included visits to art museums, wax anatomy museums, churches, ossuaries, and anatomy theaters (Table 1). Instruction during the site visits was provided by the course faculty or licensed tour guides. Learning activities at the sites provided students with the opportunity to deepen their anatomical knowledge by identifying and evaluating the anatomical fidelity of musculoskeletal structures depicted in artworks. Students also learned about the shared interests and common practices between Renaissance anatomists and artists, how anatomical knowledge changed from antiquity to the Renaissance, and how and why anatomy theaters were built and used.

Typically, each day began with a class session that included discussion of the previous day's experience, a short lecture on background material, and preparation for the day's site visit. In some class sessions, students worked in groups to consolidate their understanding of the material through debates, collaborative writing or presentations. Daily assignments consisted of prompts to guide students' thinking and viewing as they engaged with the artworks at the sites. During the visits, students took notes (and photos when allowed) and sometimes sketched in response to the assignment prompts. The students' work on their assignments served as the basis for evaluation of their learning in the course.

The study abroad course was advertised on the university-wide global engagement website and students from any academic unit at the university were welcome to participate. Of the 29 students participating in 2018 ($n=14$) or 2022 ($n=15$), most were Kinesiology students enrolled in the Movement Science ($n=24$) or Applied Exercise Science ($n=1$) program. Four students were enrolled in other programs (Engineering-First Year, Biomedical Engineering, Neuroscience and Nursing). Students were mostly at the sophomore ($n=12$) and junior ($n=13$) levels, but two first year and two senior

TABLE 1 Anatomy-related sites included in itinerary.

Site type	City	Site
Art Museum	Florence	Galleria dell'Accademia
	Florence	Uffizi Gallery
	Florence	Bargello Museum
	Florence	Loggia dei Lanzi
	Milan	Museo della Pietà Rondanini
	Rome	Vatican Museums
	Rome	Borghese Gallery
Wax Anatomy Museum	Florence	La Specola Museum, University of Florence
	Bologna	Wax Anatomy and Obstetrics Collection, Palazzo Poggi
	Bologna	Luigi Cattaneo Anatomical Wax Museum, Univ. of Bologna
Anatomy Theater	Bologna	Anatomical Dissection Theater, Palazzo dell'Archiginnasio
	Padua	Anatomical Theater, Palazzo Bo, University of Padua
Church	Florence	Medici Chapel, New Sacristy
	Milan	Duomo di Milano
	Rome	St. Peter's Basilica
	Rome	San Pietro in Vincoli
	Rome	Santa Maria del Popolo
Ossuary	Milan	San Bernardino alle Ossa
	Rome	Capuchin Crypt

students also participated. Although the only prerequisite was successful completion of a college-level human anatomy course, all but one student had completed the sophomore-level Movement Science course "Human Musculoskeletal Anatomy" before participating in the study abroad course.

The Institutional Review Board designated the study as Exempt. Students were informed about the research associated with their coursework and they were given the opportunity to opt-out without knowledge of the course instructors. None of the students withdrew from the study.

ASSESSMENT OF LEARNING GOALS

An important goal of the course was to provide students with the opportunity to deepen their knowledge of musculoskeletal anatomy by applying it to represented bodies in artworks. Different types of artworks offered learning experiences at different levels of complexity in Bloom's Taxonomy (Anderson et al., 2001; Krathwohl, 2002; Armstrong, 2010). For example, anatomical wax models created for didactic purposes enabled students to apply their knowledge by identifying musculoskeletal structures depicted in the artworks, a level of learning categorized as "applying" in Bloom's Taxonomy. Sculptures created for artistic or religious purposes enabled students to engage in a deeper level of learning as they evaluated the bones, muscles, or surface anatomy depicted in artworks. These learning activities required students to think critically about the fictive musculoskeletal anatomy they observed in the sculptures and draw conclusions, supported by a rationale, about the anatomical fidelity of the represented bodies. Thus, these learning activities were associated with the "evaluating" level in Bloom's Taxonomy.

Identification of musculoskeletal anatomy

Learning activities that emphasized identification of musculoskeletal structures took place during visits to the wax anatomy museums in Florence (La Specola Museum, University of Florence) and in Bologna (Wax Anatomy and Obstetrics Collection in the Palazzo Poggi Museum and Luigi Cattaneo Anatomical Wax Museum at the University of Bologna). The wax anatomy models in these museums were made by artists working closely with anatomists to mimic human anatomy for inspection by students and, in Florence, also by the public (Haviland & Parish, 1970; Chen et al., 1999; Ballestriero, 2010; Riva et al., 2010; Messbarger, 2013; Narang et al., 2021). The wax anatomy models displayed in the La Specola Museum were created entirely of wax using casts of dissected cadaver anatomy, and feature the work of Clemente Susini (1754–1814) (Poggesi, 1999, 2009). In the Palazzo Poggi Museum, the students were asked to examine the whole body models by Ercole Lelli (1702–1766), created with wax applied to human bones for instructional purposes (Maraldi et al., 2000; Dacome, 2006). In the Luigi Cattaneo Anatomical Wax Museum, students were asked to examine the wax anatomy models of limbs and joints by Susini and Giuseppe Astorri (1785–1852) (Maraldi et al., 2000; Ruggieri, 2003; Galassi et al., 2015; Aldini et al., 2019) (Figure 1). Although the wax anatomy models at all three sites were produced in the 18th and 19th centuries, they grew out of an Early Modern tradition and gave students an opportunity to apply their knowledge to important representations of musculoskeletal anatomy created by Italian artists in previous centuries.

At the La Specola museum in Florence, students had about 1 h to explore several rooms with wax anatomy models of whole bodies (standing and reclining) and smaller body parts (in 2018 only; the museum was closed for restoration in 2022). Their assignment was to select models that displayed muscles of the upper extremity, lower extremity and torso, take photos, and identify muscles on their photos (muscle identification keys were not provided with the models). The students examined 16 different models (5 whole body models and 11 models of body parts) and accurately identified 44 different muscles (Appendix 1). On average, students identified 7.3 muscles (range 3–14 muscles), with an average of 2.7 muscle identifications per model.

In Bologna, students were guided through the Wax Anatomy and Obstetrics Collection in the Palazzo Poggi Museum by a tour guide. They were given about 10 min to examine the standing figures by Lelli with progressively deeper dissections of musculature, make notes and take photos. Subsequently, students identified muscles by annotating their photos (2018 only). The instructor with an anatomy background (M.G.) determined whether muscles were identified correctly in the

FIGURE 1 Wax anatomy model by Giuseppe Astorri, Luigi Cattaneo Anatomical Wax Museum, University of Bologna (photo credit: authors).

assignments. The students correctly identified 25 different muscles, averaging 4.1 muscles per student (range 1–8 muscles) (Appendix 1).

At the Luigi Cattaneo Anatomical Wax Museum in Bologna, a tour guide introduced the students to the history of the collection, and then students were given about 45 min to explore on their own. They were asked to focus on the room with anatomical waxes of musculoskeletal structures by Astorri, Bettini, and Susini, make notes and take photos. Subsequently, students identified muscles by annotating their photos (2018 only). On average, the students examined models displayed in 2.3 cases (range 1–4 cases). The students identified 35 different muscles, averaging 6.3 accurately identified muscles per student (range 2–15 muscles) (Appendix 1).

Evaluation of anatomical fidelity

Learning activities that emphasized evaluation of anatomical fidelity included artworks representing different aspects of musculoskeletal anatomy. Students evaluated skeletal anatomy represented in sculptures on tombs in churches in Rome (Figure 2). This practice is related to the concept of memento mori. Originating in ancient Rome, memento mori ("remember that you must die") urged meditation on the brevity of life, an idea that found popular representation in Christian funerary art of the Renaissance and Early Modern periods. Human skeletal representations on tombs made a spiritual connection between the afterlife and moral living in the present. Students also evaluated superficial musculature represented in a sculpture of a flayed body, or écorché, in Milan, Marco d'Agrate's *Saint Bartholomew* (Figure 3). Écorchés are anatomical representations of the body in which the skin has been removed to reveal the underlying musculature and tissues. Though the term was coined in the 19th century, this artistic practice became popular during the Renaissance as a means for artists to demonstrate their skill in representing the body with a high degree of naturalism.

Skeletal anatomy in memento mori

Students were asked to critically evaluate the anatomical fidelity of skeletons represented in sculptures on tombs. The students were given a list of four tombs in Rome that they visited in groups of 2–4 students, without an instructor or tour guide. These tombs include the *Tomb of Giovanni Battista Gisleni* in the church of Santa Maria del Popolo, designed by the artist himself (c.1672); Gianlorenzo Bernini's *Tomb of Pope Alexander VII* in St. Peter's Basilica (1671–1678); and two tombs in the church of San Pietro in Vincoli, Carlo Bizzaccheri's *Tomb of Cardinal Cinzio Aldobrandini* (1705–1707) (Figure 2) and the *Memorial to Cardinal Mariano Pietro Vecchiarelli* (c.1667) by an unknown artist. The assignment asked students to observe each artwork, take a photo and make notes about the faithfulness of the fictive anatomy. Students submitted their assignments as groups in 2018, and as individuals

FIGURE 2 Carlo Bizzaccheri, Tomb of Cardinal Cinzio Aldobrandini (1705–1707), San Pietro in Vincoli, Rome (photo credit: authors).

in 2022. In both years, students described aspects of the artworks that they considered "incorrect" representations of skeletal anatomy. Examples of the students' explanations regarding the faithfulness of the fictive anatomy are provided in Table 2.

Muscular anatomy in écorchés

In Milan, the students were asked to consider how much artistic license was exercised by the sculptor Marco d'Agrate when designing and carving the flayed body of *St. Bartholomew* (1562), displayed in the Milan Duomo (2022 only) (Figure 3). The students examined the sculpture for about 30 min and were asked to make two lists: (1) the ways the artist departed from anatomical fidelity, and (2) the ways in which the sculpture, as an écorché, was accurate and effective. The students made notes and took photos to support their explanations.

For the "accurate" anatomy, the majority of students (71%) just listed muscle names, but a few students explained why the represented anatomy appeared correct (Table 3). In contrast, when describing "inaccurate" anatomy, most students (79%) provided explanations about how the fictive anatomy in the sculpture did not match their understanding of superficial musculature (Table 3). In addition to anatomical descriptions of inaccuracies, students also described "too many muscles" in a particular region, muscles being the wrong shape or "not running in the right direction", or muscles not being represented at all.

Surface anatomy in sculptures

In Rome, the students were asked to evaluate the anatomical fidelity of the surface anatomy depicted in artworks with an

FIGURE 3 Marco d'Agrate, Saint Bartholomew (1562), Milan Cathedral (photo credit: Scala/Mauro Ranzani/Art Resource, NY).

emphasis on representation of musculature. At St. Peter's Basilica, students spent 5–10 min looking at Michelangelo's *Pietà* (1488–1489) and then made notes describing the fictive anatomy and evaluating how faithful it was. At the Vatican Museums, students were asked to describe the anatomical fidelity of sculptures from antiquity that served as inspiration for Renaissance artists and illustrations in anatomical treatises, as they spent 5–10 min observing either the *Belvedere Torso* (ancient Roman, c.1st century BCE) or the *Laocoön and His Sons* (ancient Roman, c.30–40 BCE) (2018 only). Examples of students' evaluations of the anatomical fidelity of surface anatomy depicted in represented bodies in artworks are given in Appendix 2. Many of the students' explanations of correctly or incorrectly depicted anatomy were based on their expectations about what muscular anatomy might be observable in a person in a similar pose or completing a similar action that would engage the musculature. Other students based their rationales on their knowledge of attachment sites for muscles and how the fictive surface anatomy depicted the expected anatomical relationships.

In Florence, assignments at three sites (Galleria dell'Accademia, San Lorenzo complex, Uffizi Gallery) were designed for students to analyze muscle function as depicted in artworks. To accomplish this task, students needed to consider the position of the body and the muscles required to maintain the posture or perform the implied body movement in the sculpture, and then compare their expectations with their observations of the represented body. Thus, they had to use their knowledge of musculoskeletal anatomy to carry out an evaluation of the anatomical fidelity of bodies represented in the artworks.

At the Galleria dell'Accademia, students were asked to choose and closely observe one of the *Prisoners* by Michelangelo (1475–1564), find an example of muscle opposition, and describe how the sculpture represented muscle action (2018 only). Based on the depicted surface anatomy, students noted which muscles were apparently activated (e.g., "bulging") or not, and then analyzed whether the agonist and antagonist muscles were depicted as expected for the pose or action (Appendix 3). The most thoughtful rationales included descriptions of the forces that they predicted would be

TABLE 2 Examples of student evaluations of the anatomical fidelity of skeletons represented on tombs.

Giovanni Battista Gisleni, *Tomb of Giovanni Battista Gisleni*, c. 1672
• Looking from the perspective of an anatomist, the hands are too large in proportion to the skull. The metacarpals are equal in length to the phalanges, which is incorrect. The metacarpals should be longer in length in comparison to the phalanges. There are also fingernails on the distal phalanges, which is not normally displayed on skeletons. There are not enough carpal bones and they are also too large in size, as if some carpal bones were merged together. At the wrist, the distal ends of the radius and ulna are not portrayed correctly. In this skeleton, the distal ends of the radius and ulna are similar in size. To be anatomically correct, the ulna should become narrower toward the distal end so that it is smaller than the distal portion of the radius. There is also an anatomical discrepancy at the neck because the cervical vertebrae are much bigger and thicker than they should be. (S4,10,13)
• At first glance, the anatomy is shockingly realistic, especially when observing the skull and mandible; while the zygomatic arches may be a bit wide, the overall appearance of the skulls seems accurate with proper proportions, inclusion of the nasal cavity, coronoid process, and even an interestingly shaped glabella; the hands look less accurate with the carpals being particularly questionable; the head of the left ulna also looks wider than normal and lacks the ulnar styloid process looking more similar to the base of the radius bone; from the dorsal view of the hand, seven of the eight carpals should be visible but on the left hand only four bones of seemingly random size and shape are visible (S15)
Gian Lorenzo Bernini, *Tomb of Pope Alex VII*, 1671–1678
• The skeleton does not have 12 pairs of ribs, and the ones present are not connected correctly. The sternum is missing, therefore, the ribs do not have anywhere to fuse, so the artist assumed that they fused into the corresponding rib on the other side. The olecranon process at the head of the ulna is represented as a separate, patella-like structure. The pubis seems to be tilted down, altering the shape of the pelvic inlet. (S1,3,9)
• This skeleton seems to be generally accurate except for smaller inaccuracies/errors; the sternum is missing while instead the ribs are extended and just meet in the middle; distal phalanges have nails; knees are missing patela as the distal femur is exposed; The sacrum seems to be depicted as more lumbar vertebrae than one bone; The 1st metacarple looks like carple bones instead of the long bone that it is. (S19)
Carlo Bizzaccheri, *Tomb of Cardinal Cinzio Aldobrandini*, 1705–1707
• Anatomically, there are several issues with the skeleton. First off, the humerus is backwards, where the head of the humerus should be, there is the olecranon fossa and the medial and lateral epicondyles. Also, the tibia have two malleoli where there should only be one medial one. And finally, the clavicle and scapula are fused together, where there should be a joint. (S6,7,8)
• His left scapula does not appear properly attached since it is visible completely on the side of the left ribcage instead of on the skeleton's back; His left humerus is also strange with the end at the shoulder joint looking more like the distal end of the posterior femur; there are two "balls" instead of the single head of the humerus with a greater and lesser tubercle; It also looks like the ulna may be upside down with the olecranon process as the distal end and the ulnar head at the proximal end (S15)
• The anatomy seems fairly accurate. Looking at his clavicle, I observe the "S" shape. It curves outward and then inward as it travels laterally. The humerus does not appear to be accurate though. The head of the humerus is not fitting correctly into the glenoid fossa of the scapula. The humerus is flipped in the wrong direction, with the condyles facing the shoulder girdle. (S29)
Artist Unknown, *Memorial to Cardinal Mariano Pietro Vecchiarelli*, after 1639
• Anatomical there are a few issues with the skeletons. First off, their clavicles are attached to their humeri, when the should articulate with the scapula. Also, their pelvic hurdles [sic] appear more flattened than normal since this is a fairly flat piece, and the sculptor most likely wanted the Cardinal leaning out to be the most anterior portion of the piece. And finally, the femur heads seem to be rotated posteriorly, rather than anteriorly, which is incorrect. (S6,7,8)
• Some of the bones seem accurate, such as the femur (can see its head neck and trochanters). The pelvis seems too anteriorly tilted. In addition, the bottom sets of ribs (hanging ribs) seem to merge at the medial tips which is not accurate. The fibulas of the skeletons also seem to be angling too far away/behind the tibia. (S29)

necessary for the action depicted in the sculpture, and whether the apparently engaged musculature matched the "movement" requirements. Other rationales were based on knowledge of agonist/antagonist pairs of muscles, and application of that expected relationship onto the evaluation of muscle action in the sculpture. While at the Galleria dell'Accademia, students were also asked to observe and sketch surface details of Michelangelo's *David* (1501–1504) (2018 and 2022). Students were not asked to evaluate the sculpture for anatomical fidelity due to the intentionally exaggerated proportions of the figure's head, hands, and feet, which Michelangelo enlarged to increase the work's legibility from the high location on the dome of the Florence Cathedral where it was originally intended to be placed (Hughes, 1997). Instead, students were assigned a close-looking task in which they selected a portion of the sculpture's musculature to draw in their sketchbooks as a non-verbal means of observing and communicating anatomical details.

In advance of a visit to the Medici Chapel (New Sacristy) in the San Lorenzo Complex, students read the following critique written by Leonardo da Vinci (1452–1519) regarding the representation of musculature in paintings (c.1502), as part of an unpublished manuscript he was working on for a treatise on painting: *"It is a necessary thing for the painter, in order to be good at arranging parts of the body in attitudes and gestures which can be represented in the nude, to know the anatomy of the sinews, bones, muscle, and tendons. He should know their various movements and force, and which sinew or muscle occasions each movement, and paint those only distinct and thick, and not the others, as do many who, in order to appear to be great draughtsmen, make their nudes wooden and without grace, so that they seem a sack full of nuts rather than the surface of a human being, or indeed, a bundle of radishes rather than muscular nudes."* (da Vinci & McMahon, 1956). In the ensuing assignment, students chose one of the sculptures by Michelangelo in the New Sacristy (i.e., *Day*, *Night*, *Dawn*, *Dusk*) and spent time looking at it closely (10–15 min) (Figure 4). Then, after considering the body pose and musculature represented in the sculpture, they were asked to make notes about whether or not the sculpture they were observing might be vulnerable to such criticism (2022 only). Many of

TABLE 3 Examples of student evaluations of the anatomical fidelity of musculature represented on an écorché.

Marco d'Agrate, *St. Bartholomew*, 1562

Accurate anatomy

- Correct origin of sternocleidomastoid at the sternum and clavicle; brachialis can be clearly seen; sartorius transverses his left thigh and appears to have the correct attachments; gastrocnemius and soleus are correctly layered for a superficial view of the posterior calf (S15)
- Sartorius correctly attaches at the pes anserinus; temporalis looks great and even the muscle fibers go in multiple directions; the two heads of gastrocnemius sit on top of soleus which is depper and visible distally; peroneus longus + terius [sic] loop around the lateral maleolus while brevis [sic] directly attaches on the foot anteriorly to the lateral maleolus; sternocleidomastoid + all three scalenus muscles are accurate especially their distal attachments; the flexors all originate from one common tendon (S19)
- Rectus femoris travels down anterior thigh; sartorius is superficial, travels medially; gastrocnemius is protrayed with accurate attachment; sternocleidomastoid is shown; tensor fasciae latae is shown w/correct insertion (S28)

Inaccurate anatomy

- too many muscles where obliques (running in upward direction); too many muscles on side of knee; too many muscles on iliac crest; pectoralis major/minor inaccurate; layering of muscles above knee specifically rectus femoris; muscles where tibia should be revealed medially; too many muscles revealed on medial thigh, not superficial; forearm frontal, extra muscle, potentially supinator; extensor policis longus/brevis does not exist; missing abductor pollicis longus; too many muscles on deltoid, extra muscle on right under skin; brachialis is not exposed; tricep muscle fibers need to be going vertically but are going horizontally; back muscles depicted do not exist, they are supposed to be vertical muscles, not horizontal (S23)
- The one that is really apparent is the external obliques. They are striated latitudinally rather than longitudinally. This almost gives the impression of multiple ribs externally all the way to his iliac crest. Those striations and lumps continue down to the head of his femur. It is almost as if they are depicted as a single muscle with odd striations, when the muscles should insert on the crest to the femur as seperate muscles. Additionally, the lateral lower leg muscles are very straight up and down, and they should be wrapping more using the foot for some of them. Lastly there is an absurd amount of skin, more skin than possible, which gives the drape look. Another thing, he has wrinkles on his forehead despite having no skin, as well as a nose. His face remains the same as you cannot see things like the masseter properly—there is still a "layer" of skin covering it (S24)
- Rectus femoris should be inserting on the tibial tuberosity via the patellar tendon; his external oblique fibers should be running more downward toward his pubic symphysis; the anterior side of his lower leg seems to have extra muscles; brachioradialis, extensor carpi radialis longus & brevis, digitorum extensor, carpi ulnaris—where these muscles run appear accurate however these muscles do not seem to taper out into tendons—they stay the same width the "shrink" quickly when they reach the hand; deltoid seems to have multiple heads; his tensor fasciae latae attachment seems to be superior to where it normally is; seems to have added additional adductors, should really only clearly see gracilis & adductor longus (S29)

the students regarded the sculptures as vulnerable to the criticism, explaining that particular muscles were more prominently depicted than were necessary for carrying out the implied action (Appendix 4). The quality of students' arguments varied, with some relying on qualitative descriptions of muscle representations (e.g., "fluid") rather than use of anatomical explanations (Appendix 4).

As part of the assignment in the Uffizi Gallery, students were asked to examine three different torso sculptures (*Gaddi Torso*, 1st century BCE (ancient Greek), marble; *Doryphoros Torso*, 1st century CE (ancient Roman), basanite stone; Bartolomeo Ammannati, *Mars Gradivus*, 1559, bronze). For each object, they were asked to describe the rotation of the spine, consider the muscular effort that might be required to achieve or maintain that position, and then explain whether the musculature depicted in the object reflected the muscle action they would expect (2022 only). The students were able to adequately describe the spine positions and expected muscle activations, and draw conclusions about the represented muscle action (Appendix 5). Typically, however, the students did not provide adequate visual evidence to support their conclusions. For example, they used phrases like "appear activated" or "looked relaxed" without describing just how those attributes of muscle action were represented in the sculpture.

Student perceptions of their learning

Student perceptions of their learning were assessed with questionnaires administered anonymously on the last day of class. Questions asked students to indicate their level of agreement with subsequent statements and used a 5-point Likert scale for responses (strongly agree, agree, neutral, disagree, strongly disagree). The agree and strongly agree responses were combined as "Agree" in the analysis. The response rate was 100% on all questions for both 2018 and 2022 cohorts.

In 2018, students were given two sets of questions. The first question set asked students about the skills they might have developed in the course. In response to the statements "observing art objects improved my skills with identifying surface anatomy" and "studying art objects was helpful for deepening my knowledge of anatomy", 66.7% and 73.4% of students agreed, respectively. The second question set asked students to consider how the course might have helped them to learn particular concepts. All of the students agreed that the course helped them to better understand each of the following: (1) the relationship between technology and anatomy education, (2) cultural contexts for representing the human body, (3) the relationship between

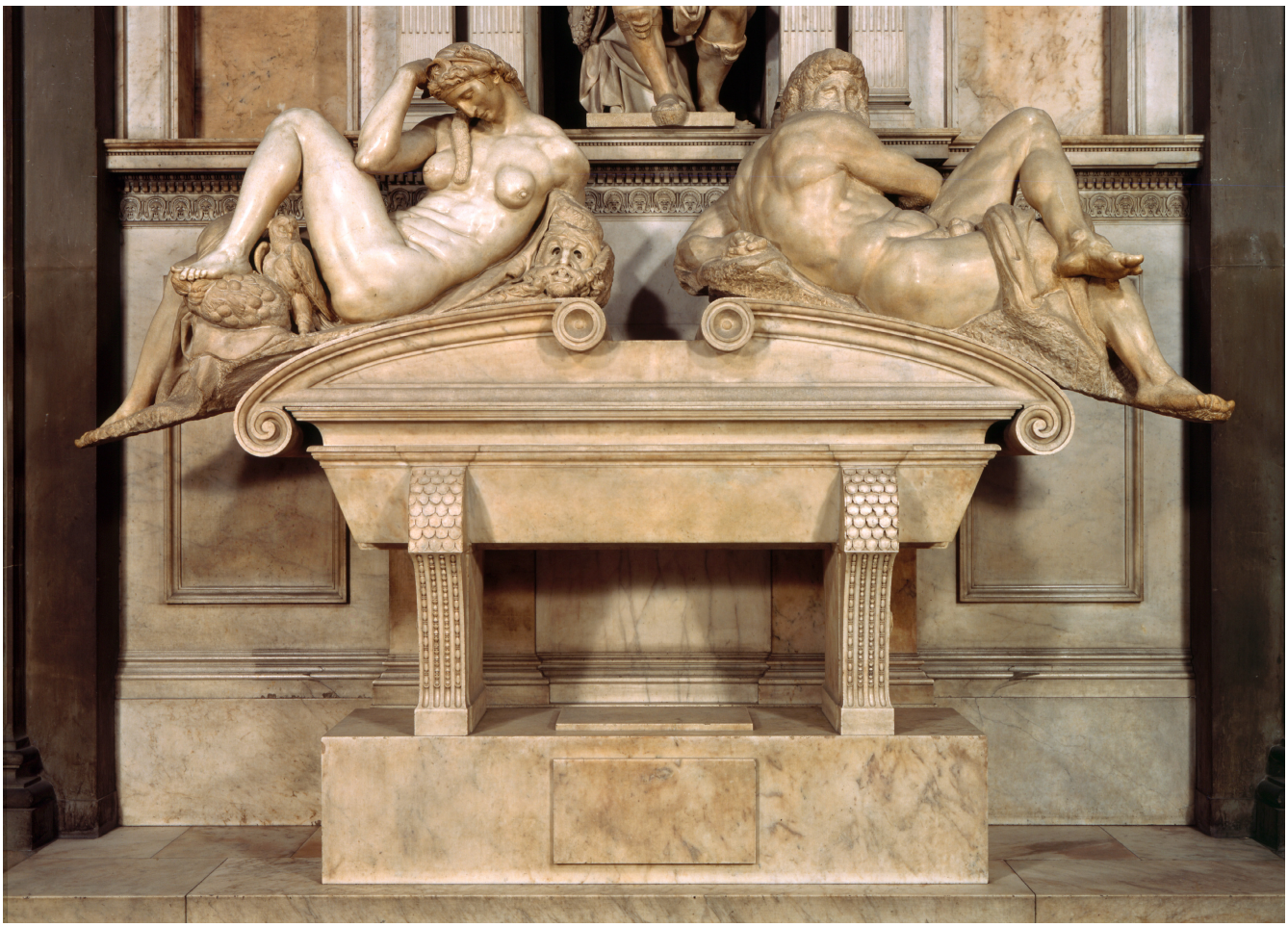

FIGURE 4 Detail of Michelangelo Buonarroti, Tomb of Giuliano de'Medici (1526–1533), Medici Chapels (New Sacristy), San Lorenzo, Florence (photo credit: Scala/Art Resource, NY).

anatomical understanding and artistic representation of the body, and (4) Renaissance contributions to advancing knowledge of musculoskeletal anatomy.

In 2022, students were asked to consider a different set of statements about how the course might have helped them learn particular concepts. The majority of students agreed that the course helped them to: (1) explain how anatomical knowledge was discovered, learned, and shared through art and science (93.3%), (2) observe and describe details of visual phenomena with greater acuity through sustained looking and critical thinking (100%), (3) understand how mediated looking affects our understanding of representations of the body (100%), and (4) articulate the parallels between represented bodies in Early Modern art and contemporary tools used in health science training (93.3%).

In 2022, students were also asked to answer some open-ended questions. In response to the question "What are the three most valuable skills you learned in this course?", a number of students acknowledged the value of applying their anatomical knowledge in the context of artworks. Some of the skills that they stated included: (1) "Formal analysis, identification of muscles through surface anatomy, the understanding of how art/anatomy are intertwined.... Additionally, looking at marble sculptures and analyzing their positions helping [sic] in my identification and understanding of muscles from a new perspective.", (2) "Being able to assess anatomy in artistic depictions, being able to apply knowledge to different mediums, being able to create an analytical way of thinking about anatomy. These skills were able to be developed though [sic] the class work in responding to prompts that guided my thought processes in what I was seeing and also causing me to reach back into previous knowledge.", and (3) "I have also learned how to apply my knowledge of anatomy to fictive artwork. These skills were bolstered by the many reflective opportunities we had in viewing artwork through museums...". Some students were able to make the connection between the anatomy-related skills that they developed in the study abroad course and its potential value for their professional futures. In response to the question "What might you say about your experience in this course when you're at an interview for a health profession or other graduate school or job interview?" students stated: (1) "It helped me make connections between what we were learning in class and the environment that I was in.", (2) "I might say this experience helped my [sic] with my ability to efficiently and effectively evaluate analyze [sic] anatomical images.", and (3) "My critical

thinking ability greatly improved and this experience has taught me to be more observant when looking in to figures related to health and the human body".

DISCUSSION

The primary goal of this study was to examine the feasibility of using represented bodies in artworks as a viable pedagogical method for teaching and learning surface anatomy. A major difference between surface anatomy presented in living bodies and represented in artworks is that represented bodies display fictive anatomy, regardless of the artist's intent (Gombrich, 2000; Summers, 2003). Thus, analyzing fictive anatomy offers students the opportunity to not only apply their musculoskeletal knowledge as they might do in a learning experience with a living body, but also urges them to think critically about anatomy when evaluating the anatomical fidelity of the represented body.

Many of the course activities were designed to support students' deep learning in anatomy. In contrast to surface learning, characterized by rote memorization (Pandey & Zimitat, 2007; Nelson Laird et al., 2008), deep learning is an approach that emphasizes higher-order learning, such as analysis, integration, synthesis, judgment and reflection, and is characterized by the intention to understand the material (Newble & Entwistle, 1986; Nelson Laird et al., 2008). In this course, students were asked to identify musculoskeletal structures depicted in wax in the wax anatomy museums, a task that could be associated with surface learning, since the wax models in all three museums have been widely acknowledged as accurate (Chen et al., 1999; Maraldi et al., 2000; Ballestriero, 2010). However, the wax musculoskeletal structures were displayed with colors, textures, and limb positioning that differed greatly from the familiar plastic models and prosected cadaver materials in their previous anatomy lab experiences. Thus, their identification tasks went beyond Bloom's level of "remembering" (Armstrong, 2010) to a higher-order assessment of the rendered anatomy that required them to apply their knowledge in a different context with a novel presentation of musculoskeletal anatomy. While doing so, the students encountered the influence of social and cultural factors that impacted the "realistic" representations of anatomy in wax in the past, inviting them to consider the factors that might affect the "realistic" portrayals of anatomy in their contemporary textbooks, lab models, and online, digital anatomy apps, and to integrate past and present ideas about how best to represent anatomy.

In the memento mori learning activities, the students were presented with musculoskeletal structures that were created for artistic, religious, and/or social, rather than didactic, purposes. Using their knowledge, the students were able to identify errors in the anatomical representations, such as inaccurate depictions of carpals and distal radius and ulna, sternum and articulations of ribs, shape of proximal humerus (Figure 2), and articulations of clavicle, scapula and proximal humerus (Table 2). Even when students recognized differences between their remembered anatomy and the depicted anatomy, however, the language used in their descriptions revealed differences in the depth of their anatomical knowledge, as well as their ability to communicate their knowledge using anatomical language. For example, when describing the apparent discrepancy in the depiction of the humerus in the *Tomb of Cardinal Cinzio Aldobrandini* (Figure 2), student descriptions varied from "…left humerus is upside down; the distal end is shown proximally" to "…the flipped humorous [sic]. The articulating facets for the olecranon process of the ulna and the head of the radius has been mistakenly placed at the shoulder girdle side of the joint. The bone has simply been rotated 180 degrees. This rotation then caused the artist to reconstruct a glenoid fossa to fit this false articulation". Thus, these learning activities exposed weaknesses in some students' anatomical knowledge, and provided instructors with new possibilities for feedback to support the students' learning.

Another approach to higher-order learning in the course was integrative learning (Miller, 2005; Huber et al., 2007), in which students were challenged to blend concepts from art history and anatomy. In one assignment, students were asked to provide anatomical evidence in support of their argument whether the anatomy portrayed in the *St. Bartholomew* sculpture (Figure 3) was accurate, as expected in an écorché, or was inaccurate, subject to the artist's intent. In another assignment, students were asked to consider whether musculature depicted in some Michelangelo sculptures (Figure 4) were vulnerable to Leonardo's critique of portrayals of musculature by other artists. Both of these assignments posed questions that required the students to integrate musculoskeletal anatomy and art history concepts, using both anatomical and visual data to construct their answers, extending the reach of the students' anatomical expertise far beyond the classroom and into new humanistic domains.

As part of their anatomical fidelity analyses, students were asked in some assignments to assess muscle action as it might be portrayed in a represented body in an artwork. An important difference between assessing muscle action in a living body and a represented body, of course, is absence of touch. With their own bodies, students can use palpation to self-examine whether a muscle is activated (Canoso et al., 2020). With an artwork, however, students had only their observations to deduce whether the portrayed muscles might be active. Rather than a limitation, this pedagogical modality created a critical thinking challenge for the students. To complete the task, students needed to consider the body movement implied in a sculpture, recall which muscles might be engaged in controlling such a posture or a movement, and then assess whether or not the muscles represented in the sculpture were depicted in a way that was consistent with their expectations about muscle function. Thus, the analyses and judgments required of students in these learning activities created opportunities for more deep learning.

When evaluating the anatomical fidelity of the artworks, students experienced learning in a context without a "correct" answer, that is, the students needed to critically select and use knowledge effectively to generate their response. This approach to learning is consistent with constructivism, a set of ideas about learning sharing the common view that the acquisition of knowledge is actively

constructed by individuals or social communities and is not a passive reception of information (Hein, 1991; Tynjälä, 1999; Terrell, 2006; Bada & Olusegun, 2015). Bergman et al. (2013) demonstrated principles of constructivism that are relevant to learning surface anatomy, including contextual learning (i.e., learners should be exposed to professionally relevant context, especially from multiple perspectives) and collaborative learning (i.e., learners should interact with each other). Similarly, in this course, students connected the learning activities with their professional aspirations. Because the concepts related to art history were new to these students, as well as the use of artworks as objects for learning anatomy, the students often collaborated by discussing the assignment prompts, either informally while viewing the artworks or formally in the group-based assignments.

In addition to examination of the students' responses to the assignment prompts, the students' perceptions of their learning provided another assessment of the effectiveness of the pedagogical approaches used in the course. The majority of students in 2018 reported that evaluating the anatomical fidelity of represented bodies in artworks supported their learning of surface anatomy and musculoskeletal anatomy. In 2022, using an open-ended response format, many students reported that their analytical and critical thinking skills had improved in the course, particularly with regard to representations of the body. Perceived improvements in students' critical thinking skills may have been linked to the assignments requiring the identification of anatomical inaccuracies in some Renaissance artworks, and the integrative course material that encouraged students to evaluate differences and shared commonalities in representing the body during the Early Modern period and the present day. The assignments enabled students to deepen their musculoskeletal and surface anatomy knowledge, perhaps contributing to their perceptions of the learning value of the course.

The pedagogies in this course were also aligned with all three themes identified by Abu Bakar et al. (2022) as effective for teaching of surface anatomy, that is, contextualized teaching, experiential learning, and learning facilitation. Elements of contextualized teaching in this course included authentic contextualization as evidenced by student statements about the relevance of the skills they learned in the course to their future careers, an interactive environment including peer interactions in the group assignments, and active learning through participation in class discussions and team activities both in and out of class sessions. Elements of experiential learning in the course included the site-based learning activities in which students observed artworks from multiple angles and distances, and reflections on their observations in the assignment prompts. Finally, the students' learning was facilitated by instructors with expertise in both anatomy and history of art, helping them to better understand the relationship between the anatomy that they observed in the represented bodies, and the socio-cultural factors informing the artists' work.

Others have established that multimodal learning is a particularly effective approach to teaching surface anatomy (Sugand et al., 2010; Anderton et al., 2016; Abu Bakar et al., 2022). The pedagogies used in this study abroad course offer an additional modality, based on the fictive anatomy in represented bodies in artworks. Although the artworks used in this course were found in cultural institutions in Italy, these art-based pedagogies may be available to anatomy educators at any institution with a nearby art museum. Partnering with museum education staff may provide the support needed for an anatomist to create an adjunctive learning experience for their undergraduate students. While this course focused primarily on three-dimensional artworks, paintings and works on paper also provide students with valuable opportunities to evaluate represented anatomy, notably through the prints of Vesalius and drawings by Leonardo and Michelangelo. This course emphasized an in-person experience of artworks, which allowed students the best conditions for evaluating anatomical fidelity through looking closely at crucial details such as relative scale, surface texture, and modeling. It remains to be determined whether students would derive similar benefit from viewing these artworks reproduced in digital images. Digital reproductions remain a mainstay for teaching within the field of art history, though their limitations with respect to faithfully representing what they depict, as well as their distorting qualities, are widely recognized (D'Alleva, 2006).

Limitations

This study is limited by the relatively small number of students that participated in the study abroad course in the two years that it was offered. The majority of students were in kinesiology, so whether the pedagogical approach would be effective for undergraduate students in other academic programs is not known. Given the qualitative nature of their assignments and prompts, the impact of the learning activities could only be inferred through faculty assessment of student submissions and the students' own perceptions of their learning. Since the learning activities were tightly coupled with the artworks associated with the site visits, the assignments were ordered by the travel itinerary rather than pedagogical design, shifting the introduction of concepts in the course from ideal to pragmatic.

Because the evaluation surveys were administered anonymously, it was not possible to connect individual students' perceptions of their learning with the learning outcomes, which limits the ability to examine the relationship between learning activities and learning outcomes. Ideally, individual student learning would be assessed by tracking their responses to assignment prompts as the course progressed, so that the effectiveness of the course (and individual assignments) toward meeting the learning objectives could be evaluated. In future iterations of the course, student privacy could be maintained when assessing individual student learning by assigning a code to each student and then analyzing the deidentified student work.

CONCLUSIONS

Despite these limitations, this study demonstrates that using represented bodies in artworks is a feasible pedagogical modality

for deepening students' knowledge of musculoskeletal anatomy and learning surface anatomy. Further, students' evaluation of the anatomical fidelity of fictive anatomy in represented bodies in art provides an opportunity for developing their critical thinking skills.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest.

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REFERENCES

Abu Bakar YI, Hassan A, Yusoff MSB, Kasim F, Sulong HAM, Hadie SNH. A scoping review of effective teaching strategies in surface anatomy. Anat Sci Educ. 2022;7:166–77.

Adkins J. Authenticity in anatomy art. J Med Hum. 2017;40:117–38.

Agarwal GC, McNulty M, Santiago KM, Torrents H, Caban-Martinez AJ. Impact of visual thinking strategies (VTS) on the analysis of clinical images: a pre-post study of VTS in first-year medical students. J Med Hum. 2020;41:561–72.

Aggarwal R, Brough H, Ellis H. Medical student participation in surface anatomy classes. Clin Anat. 2006;19:627–31.

Aka JJ, Cookson NE, Hafferty FW, Finn GM. Teaching by stealth: utilising the hidden curriculum through body painting within anatomy education. Eur J Anat. 2018;22:173–82.

Aldini NN, Galassi FM, Armocida E, Ruggeri A. Giuseppe Astorri, wax modeller of the University of Bologna, and his preparations on the musculoskeletal apparatus. New investigations on an antique heritage. Musei d'Etruria: Atti del XXVI Convegno internazionale di studi sulla storia e l'archeologia dell'Etruria: Vol. XXVI. Rome: Nella Sede Della Fondazione; Edizioni Quasar; 2019.

Anderson LW, Krathwohl DR, Airasian PW, Cruikshank KA, Mayer RE, Pintrich PR, et al. A taxonomy for learning, teaching, and assessing: a revision of Bloom's taxonomy of educational objectives. New York: Longman; 2001.

Anderton RS, Chiu LS, Aulfrey S. Student perceptions to teaching undergraduate anatomy in health sciences. Int J High Educ. 2016;5:201.

Armstrong P. Bloom's taxonomy. Nashville, TN: Vanderbilt University Center for Teaching; 2010. Available from: https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/. Accessed 19 Feb 2023

Azer SA. Learning surface anatomy: which learning approach is effective in an integrated PBL curriculum? Med Teach. 2011;33:78–80.

Azer SA. The place of surface anatomy in the medical literature and undergraduate anatomy textbooks: textbooks and literature on surface anatomy. Anat Sci Educ. 2013;6:415–32.

Azzolini M. Leonardo da Vinci's anatomical studies in Milan: a re-examination of sites and sources. In: Givens JA, Reeds K, Touwaide A, editors. Visualizing medieval medicine and natural history, 1200–1550: Vol. AVISTA Studies in the History of Medieval Technology, Science and Art Vol. 5. Aldershot, England: Ashgate; 2006. p. 147–76.

Backhouse M, Fitzpatrick M, Hutchinson J, Thandi CS, Keenan ID. Improvements in anatomy knowledge when utilizing a novel cyclical "observe-reflect-draw-edit-repeat" learning process. Anat Sci Educ. 2017;10:7–22.

Bada SO, Olusegun S. Constructivism learning theory: a paradigm for teaching and learning. J Res Meth Educ. 2015;5:66–70.

Ballestriero R. Anatomical models and wax Venuses: art masterpieces or scientific craft works? J Anat. 2010;216:223–34.

Bardes CL, Gillers D, Herman AE. Learning to look: developing clinical observational skills at an art museum. Med Educ. 2001;35:1157–61.

Bareither ML, Arbel V, Growe M, Muszczynski E, Rudd A, Marone JR. Clay modeling versus written modules as effective interventions in understanding human anatomy. Anat Sci Educ. 2013;6:170–6.

Barmaki R, Yu K, Pearlman R, Shingles R, Bork F, Osgood GM, et al. Enhancement of anatomical education using augmented reality: an empirical study of body painting. Anat Sci Educ. 2019;12:599–609.

Bergman EM, Sieben JM, Smailbegovic I, de Bruin ABH, Scherpbier AJJA, van der Vleuten CPM. Constructive, collaborative, contextual, and self-directed learning in surface anatomy education. Anat Sci Educ. 2013;6:114–24.

Black E, Varsou O. Dissecting art: developing object-based teaching using historical collections. In: Rea P, editor. Biomedical visualization. Vol 5. Advances in Experimental Medicine and Biology. Vol 1205. Crusio WE, Lambris JD, Rezaei N, Series editors. Cham, Switzerland: Springer; 2019. p. 79–92.

Boon JM, Meiring JH, Richards PA. Clinical anatomy as the basis for clinical examination: development and evaluation of an introduction to clinical examination in a problem-oriented medical curriculum. Clin Anat. 2002;15:45–50.

Canoso JJ, Saavedra MA, Pascual-Ramos V, Sanchez-Valencia MA, Kalish RA. Musculoskeletal anatomy by self-examination: a learner-centered method for students and practitioners of musculoskeletal medicine. Ann Anat. 2020;228:151457.

Carvalho Filho MA, Hafferty FW, Pawlina W. Anatomy 3.0: rediscovering Theatrum Anatomicum in the wake of Covid-19. Anat Sci Educ. 2021;14:528–35.

Chen JCT, Amar AP, Levy M, Apuzzo MLJ. The development of anatomic art and sciences: the ceroplastica anatomic models of La Specola. Neurosurgery. 1999;45:883–92.

Cookson NE, Aka JJ, Finn GM. An exploration of anatomists' views toward the use of body painting in anatomical and medical education: an international study. Anat Sci Educ. 2018;11:146–54.

da Vinci L, McMahon AP. Treatise on painting. (Codex urbinas latinus 1270). Translation. Princeton, NJ: Princeton University Press; 1956.

Dacome L. Waxworks and the performance of anatomy in mid-18th-century Italy. Endeavour. 2006;30:29–35.

D'Alleva A. Look!: the fundamentals of art history. 2nd ed. Upper Saddle River, NJ: Prentice Hall; 2006.

DeHoff ME, Clark KL, Meganathan K. Learning outcomes and student-perceived value of clay modeling and cat dissection in undergraduate human anatomy and physiology. Adv Physiol Educ. 2011;35:68–75.

Diaz CM, Woolley T. Engaging multidisciplinary first year students to learn anatomy via stimulating teaching and active, experiential learning approaches. Med Sci Educ. 2015;25:367–76.

Evans DJR, Pawlina W, Lachman N. Human skills for human[istic] anatomy: an emphasis on nontraditional discipline-independent skills. Anat Sci Educ. 2018;11:221–4.

Ferrari G. Public anatomy lessons and the carnival: the anatomy theatre of Bologna. Past Present. 1987;117:50–106.

Finn GM. Twelve tips for running a successful body painting teaching session. Med Teach. 2010;32:887–90.

Finn GM. Current perspectives on the role of body painting in medical education. Adv Med Educ Prac. 2018;9:701–6.

Finn GM, McLachlan JC. A qualitative study of student responses to body painting. Anat Sci Educ. 2009;3:33–8.

Galassi F, Ruggeri A, Petti K, Ashrafian H. Marvels of the Bologna anatomical wax museum: their theoretical and clinical importance in the training of 21st century medical students. HAPS Educ. 2015;19:4–9.

Ganguly PK, Chan LK. Living anatomy in the 21st century: how far can we go? S-E Asian J Med Educ. 2008;2:52–7.

George BM, Nayak SB, Venketesan P, Marpalli S, Rao MKG. Impact of living (surface) anatomy module as continuous professional development program for practicing physiotherapists. J Datta Meghe Ins Med Sci Univ. 2019;14:16–21.
Ghosh SK. Evolution of illustrations in anatomy: a study from the classical period in Europe to modern times. Anat Sci Educ. 2014;8:175–88.
Gombrich EH. Art and illusion: a study in the psychology of pictorial representation. Millennium ed. Princeton, NJ: Princeton University Press; 2000.
Gurwin J, Revere KE, Niepold S, Bassett B, Mitchell R, Davidson S, et al. A randomized controlled study of art observation training to improve medical student ophthalmology skills. Ophthalmol. 2018;125:8–14.
Haidet P, Jarecke J, Adams NE, Stuckey HL, Green MJ, Shapiro D, et al. A guiding framework to maximise the power of the arts in medical education: a systematic review and metasynthesis. Med Educ. 2016;50:320–31.
Hall J. Bodies. Michelangelo and the reinvention of the human body. 1st American ed. New York, NY: Farrar, Straus and Giroux; 2005. p. 63–102.
Harcourt G. Andreas Vesalius and the anatomy of antique sculpture. Representations. 1987;17:28–61.
Haviland TN, Parish LC. A brief account of the use of wax models in the study of medicine. J Hist Med Allied Sci. 1970;25:52–75.
Hein GE. Constructivist learning theory. Institute for Inquiry. 1991 Available from: http://www.exploratorium.edu/ifi/resources/constructivistlearning.html
Huber MT, Hutchings P, Gale R, Miller R, Breen M. Leading initiatives for integrative learning. Lib Educ. 2007;93:46–51.
Hughes A. Michelangelo. London: Phaidon Press; 1997. p. 70–4.
Jariyapong P, Punsawad C, Bunratsami S, Kongthong P. Body painting to promote self-active learning of hand anatomy for preclinical medical students. Med Educ Online. 2016;21:30833.
Jasani SK, Saks NS. Utilizing visual art to enhance the clinical observation skills of medical students. Med Teach. 2013;35:e1327–31.
Klestinec C. A history of anatomy theaters in sixteenth-century Padua. J Hist Med Allied Sci. 2004;59:375–412.
Kooloos JGM, Schepens-Franke AN, Bergman EM, Donders RART, Vorstenbosch MATM. Anatomical knowledge gain through a clay-modeling exercise compared to live and video observations: clay modeling, live and video observation. Anat Sci Educ. 2014;7:420–9.
Kotzé SH, Mole CG, Greyling LM. The translucent cadaver: an evaluation of the use of full body digital x-ray images and drawings in surface anatomy education. Anat Sci Educ. 2012;5:287–94.
Krathwohl DR. A revision of Bloom's taxonomy: an overview. Theory Prac. 2002;41:212–8.
Lazarus PA, Rosslyn FM. The arts in medicine: setting up and evaluating a new special study module at Leicester Warwick Medical School. Med Educ. 2003;37:553–9.
Maraldi NM, Mazzotti G, Cocco L, Manzoli FA. Anatomical waxwork modeling: the history of the Bologna anatomy museum. Anat Rec. 2000;261:5–10.
McLachlan JC, Regan De Bere S. How we teach anatomy without cadavers. Clin Teach. 2004;1:49–52.
McMenamin PG. Body painting as a tool in clinical anatomy teaching. Anat Sci Educ. 2008;1:139–44.
Messbarger R. The re-birth of Venus in Florence's Royal Museum of physics and natural history. J Hist Coll. 2013;25:195–215.
Miller R. Integrative learning and assessment. Peer Rev. 2005;7:11–4.
Moore CM, Lowe C, Lawrence J, Borchers P. Developing observational skills and knowledge of anatomical relationships in an art and anatomy workshop using plastinated specimens. Anat Sci Educ. 2011;4:294–301.
Naghshineh S, Hafler JP, Miller AR, Blanco MA, Lipsitz SR, Dubroff RP, et al. Formal art observation training improves medical students' visual diagnostic skills. J Gen Intern Med. 2008;23:991–7.
Nanjundaiah K. Body-painting: a tool which can be used to teach surface anatomy. J Clin Diag Res. 2012;6:1405–8.
Narang P, Raju B, Jumah F, Konar SK, Nagaraj A, Gupta G, et al. The evolution of 3D anatomical models: a brief historical overview. World Neurosurg. 2021;155:135–43.
Naug HL, Colson NJ, Donner DG. Promoting metacognition in first year anatomy laboratories using plasticine modeling and drawing activities: a pilot study of the "blank page" technique. Anat Sci Educ. 2011;4:231–4.
Nayak SB, Kodimajalu S. Progressive drawing: a novel "lid-opener" and "monotony-breaker.". Anat Sci Educ. 2010;3:326–9.
Nelson Laird TF, Shoup R, Kuh GD, Schwarz MJ. The effects of discipline on deep approaches to student learning and college outcomes. Res High Educ. 2008;49:469–94.
Newble DI, Entwistle NJ. Learning styles and approaches: implications for medical education. Med Educ. 1986;20:162–75.
Nicholson LL, Reed D, Chan C. An interactive, multi-modal anatomy workshop improves academic performance in the health sciences: a cohort study. BMC Med Educ. 2016;16:7.
Op Den Akker JW, Bohnen A, Oudegeest WJ, Hillen B. Giving color to a new curriculum: bodypaint as a tool in medical education. Clin Anat. 2002;15:356–62.
Pandey P, Zimitat C. Medical students' learning of anatomy: memorisation, understanding and visualisation. Med Educ. 2007;41:7–14.
Park K. The criminal and the saintly body: autopsy and dissection in renaissance Italy. Renaissance Quart. 1994;47:1–33.
Pesta D. Resurrecting vivisection: Michelangelo among the anatomists. Sixteenth Cent J. 2014;45:921–50.
Poggesi M. The wax figure collection in "La Specola" in Florence. Encyclopedia Anatomica: Museo La Specola Florence. Tashen: Cologne, Germany; 1999. p. 6–24.
Poggesi M. The anatomical wax collection. In: Barsanti G, Chelazzi G, editors. The Natural History Museum of the University of Florence: the collections of the Specola: zoology and anatomical waxes. Florence, Italy: Firenze University Press; 2009. p. 81–105.
Rabattu P, Debarnot U, Hoyek N. Exploring the impact of interactive movement-based anatomy learning in real classroom setting among kinesiology students. Anat Sci Educ. 2023;16:148–56.
Riva A, Conti G, Solinas P, Loy F. The evolution of anatomical illustration and wax modelling in Italy from the 16th to early 19th centuries. J Anat. 2010;216:209–22.
Ruggieri A. The Anatomical Wax Model Museum "Luigi Cattaneo". 2nd ed. Bologna, Italy: Asterisco; 2003. p. 16.
Shapiro L, Bell K, Dhas K, Branson T, Louw G, Keenan ID. Focused multisensory anatomy observation and drawing for enhancing social learning and three-dimensional spatial understanding. Anat Sci Educ. 2020;13:488–503.
Shapiro L, Hobbs E, Keenan ID. Transforming musculoskeletal anatomy learning with haptic surface painting. Anat Sci Educ. 2023;13:488–503.
Speed CJ, Kleiner A, Macaulay JO. Broadening student learning experiences via a novel cross-disciplinary art and anatomy education program—a case study. Int J High Educ. 2015;4:86–91.
Standring S. Evidence-based surface anatomy. Clin Anat. 2012;25:813–5.
Sugand K, Abraham P, Khurana A. The anatomy of anatomy: a review for its modernization. Anat Sci Educ. 2010;3:83–93.
Summers D. Representation. In: Nelson RS, Shiff R, editors. Critical terms for art history. 2nd ed. Chicago, IL: University of Chicago Press; 2003. p. 3–19.
Terrell M. Anatomy of learning: instructional design principles for the anatomical sciences. Anat Rec. 2006;289B:252–60.
Tynjälä P. Towards expert knowledge? A comparison between a constructivist and a traditional learning environment in the university. Int J Educ Res. 1999;31:357–442.
Viana RB, Campos MH, Santos DAT, Xavier ICM, Vancini RL, Andrade MS, et al. Improving academic performance of sport and exercise

science undergraduate students in gross anatomy using a near-peer teaching program. Anat Sci Educ. 2019;12:74–81.

Zazulak J, Halgren C, Tan M, Grierson LEM. The impact of an arts-based programme on the affective and cognitive components of empathic development. Med Humanit. 2015;41:69–74.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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